International Journal of Solids and Structures 48 (2011) 1534–1543

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Dynamic fracture of concrete – compact tension specimen

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ARTICLE INFO

Article history:
Received 1 September 2010
Received in revised form 10 December 2010
Available online 4 February 2011

Keywords:
Concrete
Compact tension specimen
Dynamic fracture
Rate sensitivity
Crack branching
Finite element analysis
Microplane model

ABSTRACT

The behavior of concrete structures is strongly influenced by the loading rate. Compared to quasi-static loading concrete loaded by impact loading acts in a different way. First, there is a strain-rate influence on strength, stiffness, and ductility, and, second, there are inertia forces activated. Both influences are clearly demonstrated in experiments. Moreover, for concrete structures, which exhibit damage and fracture phenomena, the failure mode and cracking pattern depend on loading rate. In general, there is a tendency that with the increase of loading rate the failure mode changes from mode-I to mixed mode. Furthermore, theoretical and experimental investigations indicate that after the crack reaches critical speed of propagation there is crack branching. The present paper focuses on 3D finite-element study of the crack propagation of the concrete compact tension specimen. The rate sensitive microplane model is used as a constitutive law for concrete. The strain-rate influence is captured by the activation energy theory. Inertia forces are implicitly accounted for through dynamic finite element analysis. The results of the study show that the fracture of the specimen strongly depends on the loading rate. For relatively low loading rates there is a single crack due to the mode-I fracture. However, with the increase of loading rate crack branching is observed. Up to certain threshold (critical) loading rate the maximal crack velocity increases with increase of loading rate, however, for higher loading rates maximal velocity of the crack propagation becomes independent of the loading rate. The critical crack velocity at the onset of crack branching is found to be approximately 500 m/s.

1. Introduction

There are various loading schemes, which are indicated as static, monotonic, dynamic, cyclic, impulsive, and maybe some more. Impact loading is a special case of dynamic loading and impulsive loading. Impact is associated with the collision of an object with a structure. The collision can be such that the object deforms considerably, which is indicated as soft impact and it can be such that the object does merely deform which causes a hard impact. The transition between the one and the other is smooth and depends on various parameters. The acting force on the structure depends strongly on the degree of deformation of the colliding object. When an impact is simulated numerically the collision of an object is often modelled by force acting on the surface of a structure or by prescribed displacement of the surface. The force or displacement is imposed at various rates, which means that a soft and a hard impact can be simulated. This method will be applied in the here discussed example (compact tension specimen).

The response of structures depends on time dependent loading through three different effects (Reinhardt, 1982; Bischoff and Perry, 1991; Weerheijm, 1992; Ožbolt and Reinhardt, 2005, 2006; Pedersen et al., 2006; Larcher, 2009; Pedersen, 2009; *fib*, 2010): (1) through the rate dependency of the growing micro-cracks (influence of inertia at the micro-crack level), (2) through the viscous behaviour of the bulk material between the cracks (creep of concrete or viscosity due to the water content) and (3) through the influence of structural inertia forces, which can significantly change the state of stresses and strains of the material. The first two effects can be accounted for by the constitutive law and the third effect should be automatically accounted for through dynamic analysis where the constitutive law interacts with structural inertia forces. Depending on the material type and the loading rate, the first, second or third effect may dominate. For quasi-brittle materials, such as concrete, which exhibit cracking and damage phenomena, the first two effects are important for relatively low and medium strain rates. However, for higher strain rates (impact) the last effect dominates.

Regardless of the influence of strain rate, the complex transfer of energy between two or more colliding bodies or in case of explosion is an additional problem. For this reason, strain rate is not the only problem to be considered. According to Bentur et al. (1987) and Banthia et al. (1987), because of very high strain gradients it is experimentally difficult to meet the energy balance for very high loading rates. In contrary to this, numerically is relatively simple to

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doi:10.1016/j.ijsolstr.2011.01.033